Sacramento-San Joaquin Delta
Regional Ecosystem Restoration Implementation Plan

Semi-Final Species Life History Conceptual Model

Sacramento Splittail
Pogonichthys macrolepidotus

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Status of Peer Review: Model has not yet fully completed the peer review and collegial review process and final modifications may be required of the developers. Model may not be cited or circulated until that process is complete. It may be used in identifying and evaluating restoration actions with assistance from content experts. Model is appropriate for use by experienced evaluation team with input from content experts as necessary.

DO NOT CITE

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PREFACE

This Conceptual Model is part of a suite of conceptual models which collectively articulate the current scientific understanding of important aspects of the Sacramento-San Joaquin River Delta ecosystem. The conceptual models are designed to aid in the identification and evaluation of ecosystem restoration actions in the Delta. These models are designed to structure scientific information such that it can be used to inform sound public policy.

The Delta Conceptual Models include both ecosystem element models (including process, habitat, and stressor models) and species life history models. The models were prepared by teams of experts using common guidance documents developed to promote consistency in the format and terminology of the models http://www.delta.dfg.ca.gov/erpdeltaplan/science_process.asp .

The Delta Conceptual Models are qualitative models which describe current understanding of how the system works. They are designed and intended to be used by experts to identify and evaluate potential restoration actions. They are not quantitative, numeric computer models that can be "run" to determine the effects of actions. Rather they are designed to facilitate informed discussions regarding expected outcomes resulting from restoration actions and the scientific basis for those expectations. The structure of many of the Delta Conceptual Models can serve as the basis for future development of quantitative models.

Each of the Delta Conceptual Models has been, or is currently being subject to a rigorous scientific peer review process. The peer review status of each model is indicated on the title page of the model.

The Delta Conceptual models will be updated and refined over time as new information is developed, and/or as the models are used and the need for further refinements or clarifications are identified.

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Introduction

The purpose of this conceptual model is to aid management decisions for the continued persistence and recovery of Sacramento splittail. This model, along with the suite of models developed through ERP as well as other information and tools, is intended to be used for evaluating proposed restoration actions for the Delta and throughout the species geographic range. It is a qualitative life-cycle conceptual model that attempts to bring together many sources of information to build a comprehensive document that represents the current state of knowledge for the species. It is not a quantitative model however. It will not provide quantitative limits on species take or population number outcomes. It will only provide an indication of anticipated population response (i.e. increase or decrease with a magnitude of x or y) based on the most current scientific knowledge. With this knowledge, proposed restoration actions can be grouped and a positive population response can be developed through an adaptive management framework. The model must be read and understood in its entirety and does not provide users/readers quick solutions or answers. The entire life-cycle of the animal must be understood by decision makers if they intend to make sound choices in the future. The conceptual model diagram and associated tables can be used to focus the reader on potential species and population limiting factors given the current scientific understanding under current conditions. The model has a specific emphasis on the Delta; however the entire species range must be considered when population level responses are of concern. For this reason the geographic scope of this document is beyond the legal boundaries of the "Delta". This is not intended to be the final version of this conceptual model. As new information becomes available through research and in the scientific literature, this model will be updated as time allows providing managers with the most current information available. This conceptual model relies heavily on the extensive work done by Peter Moyle and others in their 2004 white paper Biology and Population Dynamics of Sacramento Splittail (*Pogonichthys macrolepidotus*) in the San Francisco Estuary: A Review which was published in the San Francisco Estuary and Watershed Science online journal. Content in the model is taken from that review unless otherwise indicated. These sections will be introduced with a citation to Moyle et al. 2004. This model also takes into account new research on Sacramento splittail which has occurred subsequent to the white paper.

Biology (Figure 1, 3, Table 1)

The Sacramento splittail is a Cyprinid native to California and the only surviving member of its genus. It can live 7-9 years and has a high tolerance to a wide variety of water quality parameters including salinity, temperature, and dissolved oxygen. Adult splittail are found predominantly in the Suisun Marsh but are also found in other brackish water marshes in the San Francisco Estuary as well as the fresher Sacramento-San Joaquin Delta. While in these areas splittail feed on a wide variety of invertebrates and detritus. In the spring when California's Central Valley experiences large amounts of snow melt runoff from the Sierra Nevada Mountains, adult splittail will move onto inundated flood plains in the valley to spawn. After spawning the adult fish move back downstream. The eggs that were laid on submerged vegetation begin to hatch in a few days and the larval fish grow at an accelerated rate in the warm and food rich environment. Once they have grown a few centimeters these juvenile fish begin moving off of the floodplain and downstream into similar areas as the adults. In the marsh these juvenile become sexually mature in two to three years (Figure 1 and Figure 3).

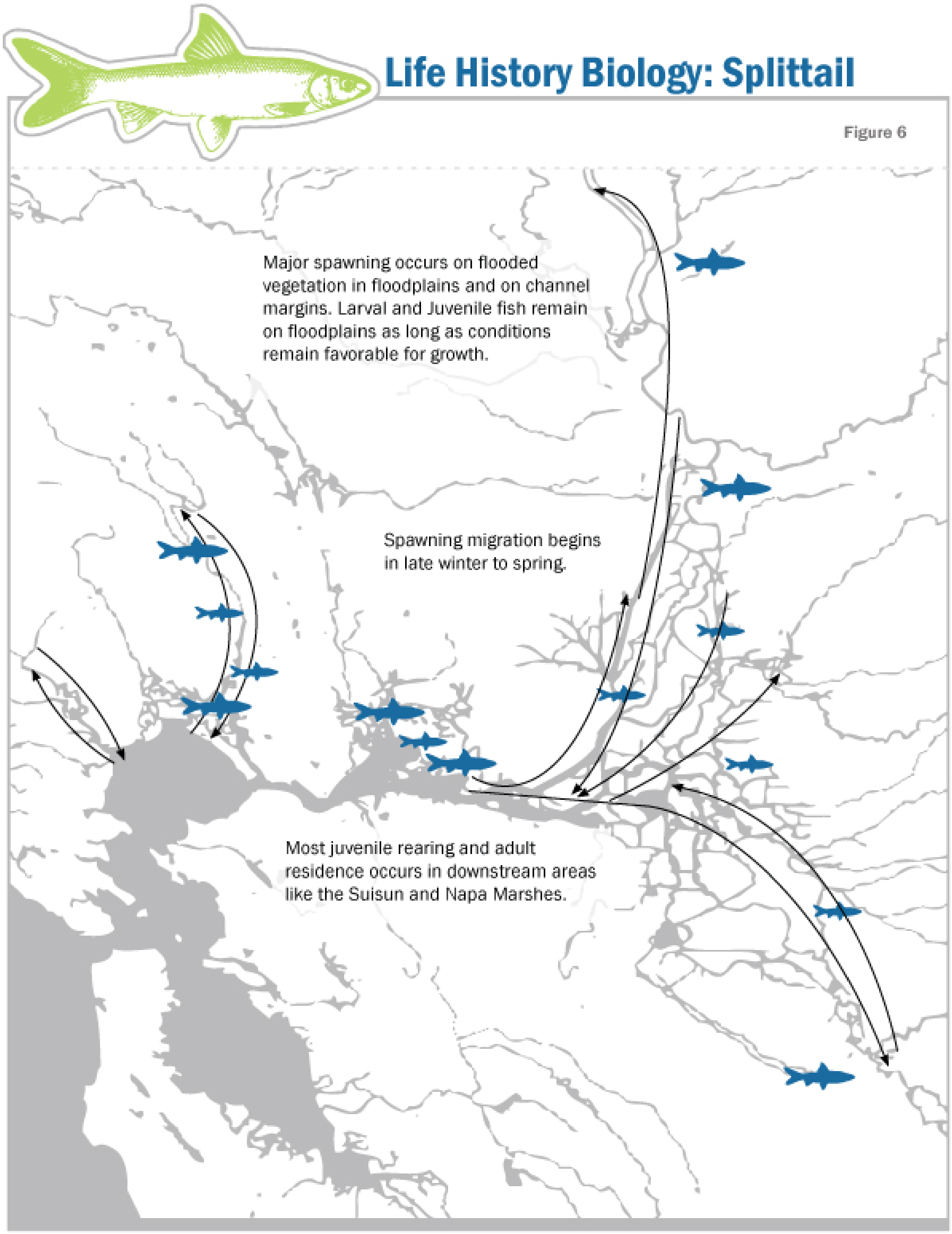

Figure 1 Life History Biology

Table 1. Life stages by biological measures

	Life stage by Biological Measures	A	B	C	D	E	F	G	H	I	J	K	L	M	N
	Habitat (*life stage*)	Dates	Age (Days post hatch)	Weight	Length (mm)	Acclimation Temperature (Celcisus)	Optimum temperatures (Celcius)	Maximun Critical Temperature	Common Salinity	Critical Salinity	Min DO Limits	Water Velocity	pH	Turbidity	References
1	Floodplain/Channel Margin (*Egg/Embryo*)	Feb - May	-3 to -5	1.55-2.04 mg	1-1.6		UNK	UNK	UNK	UNK	UNK	UNK	UNK	Unknown presumably high tolerence	Moyle et al. 2004
2	Floodplain/Channel Margin (*Larvae*)	Feb - May	0 - 5 dph		5.5-6.5 mm TL		UNK	UNK	UNK	UNK	UNK	UNK	UNK	Unknown presumably high tolerence	Moyle et al. 2004
			5 - 7 dph		7 - 8 mm TL										
3	Floodplain/Channel Margin/Delta (*Juveniles*)	Feb - July	Age - 0	0.1-0.5 g	20-30 SL	17	22	30.8	0 ppt	22.4 ppt	9-18 torr Po_2 or 0.6-1.3 mg O_2/L	3-6 Body Lengths per Second	UNK	Unknown presumably high tolerence	Young and Cech 1996
			Age - 0	0.1-0.5 g	20-30 SL	20	24	32.0							
			Age - 0	1.0-4.0 g	40-70 SL	17	21	30.0							
			Age - 0	1.0-4.0 g	40-70 SL	20	25	33.0							
4	Brackish Marsh (*Juveniles*)	Year Round	Age - 1	10-42 g	90-130 SL	12		20.5	0 ppt	23.7 ppt		3-6 Body Lengths per Second	Unknown presumably high tolerence to high pH	Unknown presumably high tolerence	Young and Cech 1996, Moyle 2002
			Age - 1	10-42 g	90-130 SL	17	20	28.9							
			Immature Age - 2	80 - 200 g	180-230 SL	12		21.9	0 ppt	28.8 ppt			Unknown presumably high tolerence to high pH	Unknown presumably high tolerence	Young and Cech 1996, Moyle 2002
			Immature Age - 2	80 - 200 g	180-230 SL	17	20	29.0	0 ppt	27.4 ppt					
5	Brackish Marsh (*Adult*)	Year Round	Mature Age 2 +		200+ SL	NA	Seasonally 5 - 24	29 - 33	2 - 18 ppt	29 ppt	< 1 mg O_2/L		Unknown presumably high tolerence to high pH	Unknown presumably high tolerence	Moyle et al. 2004, Moyle 2002
6	River (*pre-spawnAdult*)	Late Nov. - Late Jan.	Age 3 - 10		250 - 400 SL	NA	Seasonally 5 - 24	29 - 33	0 ppt	29 ppt	< 1 mg O_2/L		Unknown presumably high tolerence to high pH	Unknown presumably high tolerence	Moyle et al. 2004, Moyle 2002
7	Floodpalin/River (*Spawner*)	Feb. - Apr.	Age 3 - 10		250 - 400 SL	NA	Seasonally 5 - 24	29 - 33	0 ppt	29 ppt	< 1 mg O_2/L		Unknown presumably high tolerence to high pH	Unknown presumably high tolerence	Moyle et al. 2004, Moyle 2002
8	River/Brackish Marsh (*Post-spawn*)	Feb. - May	Age 3 - 10		250 - 400 SL	NA	Seasonally 5 - 24	29 - 33	2 - 18 ppt	29 ppt	< 1 mg O_2/L		Unknown presumably high tolerence to high pH	Unknown presumably high tolerence	Moyle et al. 2004, Moyle 2002

Distribution (see Figure 2)

The Sacramento splittail is endemic to the San Francisco Estuary and its associated watershed. Its upper known extension is to the Mud Slough on the San Joaquin at river kilometer (rkm) 201 (an additional 17rkm into Mud Slough) and to rkm 391 on the Sacramento where the Red Bluff Diversion dam exists (Feyrer et al. 2005). There are also genetically distinct populations inhabiting the Napa and Petaluma Marshes and their respective rivers (Baerwald et al. 2005).

Within the Sacramento River tributaries splittail have been documented to the following locations:

- American River to rkm 19
- Feather River to rkm 94 and from just below the Thermolito outlet (95 rkm) (Bruce Oppenheim 2003 pers comm. to Randy Baxter)
- Butte Creek/ Sutter Bypass – to vicinity of Colusa State Park

Within the San Joaquin tributaries splittail have been documented to the following locations:

- Cosumnes River – just above the confluence with the Mokelumne River (Crain et al. 2004).
- Mokelumne River – observed above Woodbridge Diversion Dam to rkm 96.

- Stanislaus River – no confirmed sightings, but based on observations from other tributaries, splittail probably inhabit low gradient portions of the lower river.
- Toulumne River – rkm 27.4 (Legion Park, Modesto, Tim Ford pers comm. to Randy Baxter) and several annually at rkm 8 1999-2002 (Tim Heyne, pers comm. to Randy Baxter).
- Merced River – rkm 20.9 several annually 1999-2001 (1.6 km upstream of Hagaman Park, Tim Heyne pers. comm. to Randy Baxter).
- A second, less studies population exist in the Napa and Petaluma Rivers and marshes (Sommer et al. 2007, Moyle et al.2004):
- Napa River – River Mile 32
- Petaluma River – River Mile 28

Splittail have extended their range in to south and central San Francisco Bay when high freshwater outflow from the Delta allow them to utilize the edges of the bay to move in water with salinities below that of sea water and have been found in Coyote Creek (Moyle et al. 2004). Historically when the Tulare Lake basin was connected to the San Joaquin River during exceptionally high outflow years, splittail were able to access this extremely productive habitat. Splittail bones have been found in Native American middens on the edges of the now extinct lake (Gobalet et al. 1993, 2004 Moyle 2002, Moyle et al. 2004).

As summarized in Moyle et al. 2004:

> In a CDFG angler survey conducted at Garcia Bend (Sacramento rkm 80.5) and upstream, 1202 adult splittail were caught during 1991-1994 and 1999-2000; 94% of these were collected during the January-March migration period (R. Baxter, unpublished data). In 1998-99, four migration pulses were indicated by peaks in catch rate in an experimental fishery at Meader's Beach (Sacramento rkm 39) that occurred in mid-December, late January, and early February, and late February (Garman and Baxter 1999). …
>
> Evidence of splittail spawning on floodplains has been found for both the San Joaquin and Sacramento rivers. In the San Joaquin drainage, spawning has apparently taken place in wet years in the region where the San Joaquin is joined by the Tuolumne and Merced rivers (T. Ford, pers. comm.; F. Ligon, pers. comm.[Sommer et al. 2007]). Larvae and small juveniles have been found in Mud and Salt sloughs within Kesterson and San Luis national wildlife refuges (USFWS, unpublished data). Presumably, spawning took place in the flooded grasslands surrounding these sloughs. Spawning has also been documented on flooded areas along the lower Cosumnes River (Crain and others 2004). Spawning may take place elsewhere in the Delta (e.g., on mid-channel islands) but it has not been documented. In the Sacramento drainage, the most important spawning areas appear to be the Yolo and Sutter bypasses, which are extensively flooded during wet years (Sommer and others 1997, 2001a [Feyrer et al. 2006]). However, some spawning takes place almost every year along the river edges and backwaters created by small increases in flow. Based on larval and beach seine sampling, splittail spawn in the Colusa to Knights Landing region of the Sacramento River in most years (Baxter 1999a; R. Baxter, unpublished data). Occasionally spawning can occur as far upstream as Hamilton City, as evidenced by sporadic collection of adult and YOY fish at a screw trap near the Glenn- Colusa Irrigation District intake (rkm 331). They apparently spawn in riparian vegetation adjacent to flooded rice fields in the lower 12 km of Sutter Bypass and in Butte Slough, based on the presence of numerous early-stage larvae during 1996, 1998, and 1999 (Baxter and Garman 1999; R. Baxter, unpublished data). Splittail may also spawn in the lower reaches of the American River when parts of the American River Parkway flood (R. Baxter, unpublished data). In the

eastern Delta, the floodplain along the lower Cosumnes River appears to be most important as spawning habitat. …

Likewise, in state and federal fish salvage facilities in the south Delta, adults are captured most frequently in January through April when they are presumably engaged in migration to and from the spawning areas. …

In 2000, they were present in permanent sloughs adjacent to the Cosumnes River floodplain for only about two weeks after leaving the floodplain and were present in large numbers at the mouth on the Mokelumne River about 2 weeks later (P. Moyle and USFWS, unpublished data). This pattern has been seen elsewhere in the system. For example, large numbers of YOY splittail are typically captured in screw traps (set at the base of floodplains) in the Sutter and Yolo bypasses in May, with diminishing numbers in June (Sommer and others 2004; CDFG unpublished data). YOY splittail are typically captured in large numbers at the SWP and CVP fish salvage operations in the south Delta in late May through mid-July, suggesting a seasonal downstream movement. By June and July, YOY splittail are present in marshes along Suisun Bay and in Suisun Marsh (Daniels and Moyle 1983; P. Moyle, unpublished data; C. Kitting, unpublished data). The downstream dispersal of YOY splittail is now well documented and particularly evident after a wet spring. A less well studied aspect of splittail life history is the small fraction of YOY spawned in the Sacramento River and Butte Creek that remain upstream through their first growing season or first year (Baxter 1999a). Age-1 splittail have been captured moving down the Sutter Bypass in spring after rearing in Butte Creek or the Sacramento River (Baxter 1999a; CDFG, unpublished data). Additional YOY have been collected in the Sacramento River beach seine survey in fall and winter (Baxter 1999a; USFWS, unpublished data). There is little evidence for riverine rearing in the San Joaquin River. …

While the preceding paragraphs indicate known collection and distribution of Sacramento splittail, it is assumed that these fish are distributed much more widely in small creeks and marshes throughout the lower portions of the watershed. Splittail are a very dynamic fish that can take advantage of myriad opportunities where habitat is concerned. Having no known collection in an area that splittail could physically access does not mean they are not there. Based on their known distribution I would assume they occur in most waterways in the Sacramento-San Joaquin watershed below dams that are still hydraulically connected to the Estuary.

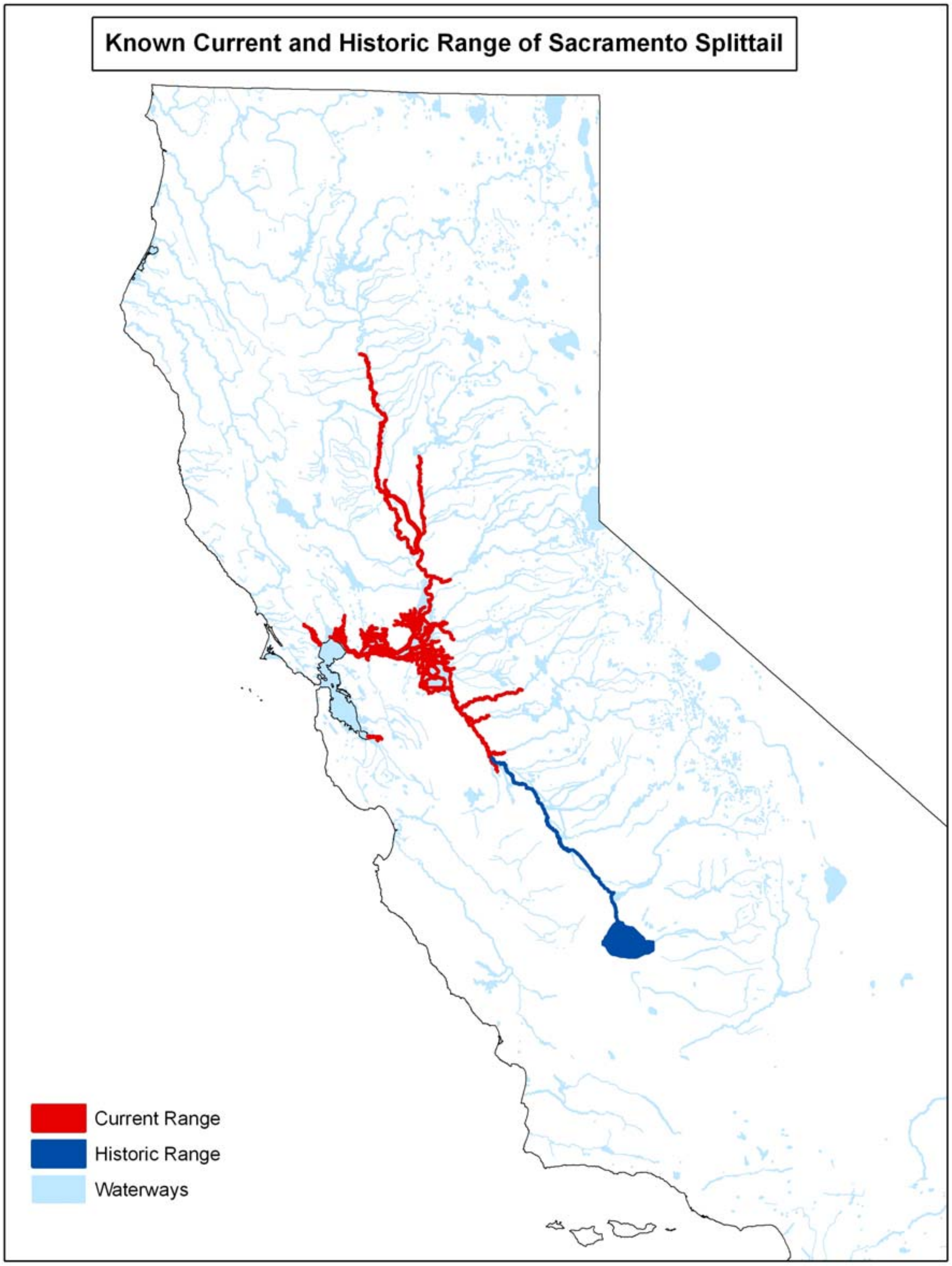

Figure 2. Known Current and Historical Range

Ecology (see *Figures 3, 4*)

Figure 3, found in this section, is a conceptual diagram meant to illustrate the dynamic life history and some of the environmental variables of splittail ecology. The left axis shows location of the various life stages and an estimated salinity found there. The top axis shows a range of temperatures which are illustrated in the figure with red shaded boxes. Temperature ranges are found within the boxes and the life history types pass through these to show how splittail interact with temperature. The dashed blue line arbitrarily delineates water year types. The Department of Water Resources classifies water years as Wet, Above Normal, Below Normal, Dry, and Critical in describing amount of precipitation for that water year. Sacramento splittail have different spawning strategies based on the amount of flood plain inundation in the watershed which is a response to the amount of precipitation and associated flood plain activation. Above the line I assume flood plain inundation and below the line I assume none. This is an arbitrary distinction. Water year type alone does not indicate the amount of flood plain inundation. The line is intended to show the distinction in spawning strategies associated with amounts of precipitation and flood plain activation. On the bottom axis there is a sliding date line. This line is not set for splittail migration, they do not posses calendars. The line is meant to give a general idea of when migration and spawning is occurring. The migration is timed more with changing photo period, increased water flows and lowering of temperatures.

It is likely that splittail are responsible for large transfers of energy from upstream floodplains into Suisun Marsh and Bay areas. These large migrations, both upstream adults and downstream juveniles are probably important in the seasonal transfer of energy within the estuary's foodweb (Feyrer et al. 2007). While this is unquantified, the sheer numbers of juvenile splittail that are found following large inundation events would indicate a significant positive impact to the downstream foodweb. It is also possible that splittail are responsible for the movement of contaminants around the system, both Selenium upstream into the Sacramento and Mercury downstream into the estuary during these migrations.

Sacramento splittail are secondary consumers throughout their life cycle and are benthic foragers most active during the day (Caywood 1974, Goals Project 2000). In Suisun Marsh adult splittail gut contents are predominantly detritus (60-79%), however, a shift has occurred since the invasion of Corbula amurensis in 1986 (Feyrer et al. 2003). After the invasion and establishment of the clam, mysid shrimp (Neomysis mercedis) populations collapsed (Kimmerer and Orsi 1996). Mysid shrimp which originally made up to 24% (average dietary importance) of splittail gut contents was reduced to 2% in the post clam period (Feyrer et al. 2003). The amount of detritus remained similar at 70% with the difference being made up with other invertebrates and Corbula (6%) itself (Feyrer et al. 2003). This shift in diet may expose splittail to higher levels of Selenium which has been implicated in reproductive stress in fishes in general and splittail (Feyrer et al. 2003, Teh et al. 2002, 2004). The nutritional importance of detritus in splittail diets is unknown. The fact that it makes up such a large portion of the gut contents indicates that it must have some nutritional value (Moyle et al. 2004). As adult splittail begin migration and movment onto inundated flood plains and channel margins, terrrestrial worms and insects become important food items (Moyle et al. 2004). Historically when splittail were more common in areas where Chinook salmon spawning was occurring splittail have been observed feeding on loose salmon eggs (Moyle et al. 2004). After yolk sac absorption the larvae begin feeding on small rotifers (Bailey 1994). Prey composition shifts as they increase in size to cladocerans and chironomid larvae (Kurth and Nobriga 2001). Larval splittail to 15mm feed heavily on zooplankton, primarily made up of cladocerans. Chironomid larvae begin to dominate after 15mm in length has been achieved (Feyrer et al. 2007). Splittail 50-100mm SL also feed primarily on detritus with calanoid and harpactocoid copepods being important as well (Moyle et al. 2004). On the Cosumnes River floodplain, the early larval period seems to coincide with large blooms of zooplankton, providing an abundant food supply (Crain et al. 2004). Splittail that rear on flood plain habitats as opposed to river margin habitats showed greater length and condition factor in the Cosumnes system (Ribeiro et al. 2004). On the Yolo bypass, seasonal inundation is accompanied by a large hatch of an endemic chironomid, Hydrobaenus saetheri Cranston and is more abundant on previously dry areas of the floodplain (Cranston et al. 2007, Benigno and Sommer 2008). This is probably an important food source for larval and juvenile splittail spawned on floodplains in the Central Valley. Age-0 splittail are strongly opportunistic feeders (Feyrer et al. 2007). Their diet changes based on habitat types occupied through ontogeny (Feyrer et al. 2007).

Larval and small juvenile splittail in flooded areas are preyed upon by an array of invertebrate predators, as well as by juveniles of both native and alien fishes that invade the areas during flood events (Moyle et al. 2004). If larval mortality rates are similar to those of other fishes, then it is likely that the vast majority of splittail die in their first few weeks of life at rates that are independent of densities of larvae but, dependent on densities of predators (Moyle et al. 2004). Stochastic environmental factors, such as sudden drops in water level that strand embryos and larvae are also important (Moyle et al. 2004). Water level may also affect predator density by expanding or contracting inundated habitat: expanded habitat should reduce predator (e.g. birds) density directly (Moyle et al. 2004). In addition, most adult alien predatory fishes such as largemouth bass (Micropterus salmoides) and bluegill (Lepomis macrochirus) seldom venture far from permanent water ways onto the flood plain (Moyle et al. 2004).

> Adult and juvenile splittail are preyed upon by piscivorous fishes and birds. Although splittail are uncommon in striped bass diets, their effectiveness as bait for striped bass has long been recognized by anglers, who fish for splittail to use them for bait. Presumably centrarchid basses, sunfish, and crappies (Pomoxis spp.) are important predators on juveniles as they leave floodplain rearing areas. Juvenile pikeminnow (Ptychocheilus grandis) and Chinook salmon are common on the floodplain and may prey on larvae and small juveniles, but this has yet to be documented. Bird predation appears limited until water recedes and floodplains begin to isolate from main channels at which point fish are exposed to wading birds. [Moyle 2004]

Hydrology is a major driver of splittail populations. Large scale spawning occurs only in years with significant inundation of flood plains in the Sacramento - San Joaquin watershed. While some small amount of spawning occurs in perennial marshes (Moyle et al. 2004) this is not enough to sustain the population in the face of its many stressors as indicated by the need to list the species during the extended drought of the 90's and associated water management (Feyrer et al 2006). Splittail are considered to be obligate flood plain spawners (Moyle 2002). Seasonal inundation of areas with a mosaic of low velocity off channel habitat types would be beneficial to this and likely other native species. They must have seasonally flooded lands on which to spawn and for early rearing of larval and juvenile fish. The ability of California water managers to manipulate flows in this system makes the dynamics of flood plain inundation extremely important to policy makers. Splittail need water levels and inundation duration in ranges that were historically present (30 - 90 days). The risk of stranding eggs and larvae on the flood plain could result in the complete loss of any benefits accrued with the initial inundation. Proper connectivity (i.e. maintaining sufficient flows to allow time for ontogenetic movement downstream of juvenile fish) of the flooded area with the main channel of the river is as important as initial flood plain inundation. This requires sufficient and constant flows onto and off of the inundated areas for a length of time required for initial rearing to occur. The minimum length of inundation is required to achieve strong year classes when associated with large scale flood plain inundation as occurs on the Yolo Bypass. Longer inundation periods allow for extended and multiple spawning events as well as other food web associated benefits. Flood plains also do not allow for residency of non-native predators. These types of habitats dry in the early summer in California (unlike the Midwest and Eastern United States where hydrology is very different) and non-native fish are unable to utilize floodplain in California in the same way as their home ranges. Managers have a unique opportunity to improve populations of a native fish with a relatively simple management option, inundation of flood plains throughout the system.

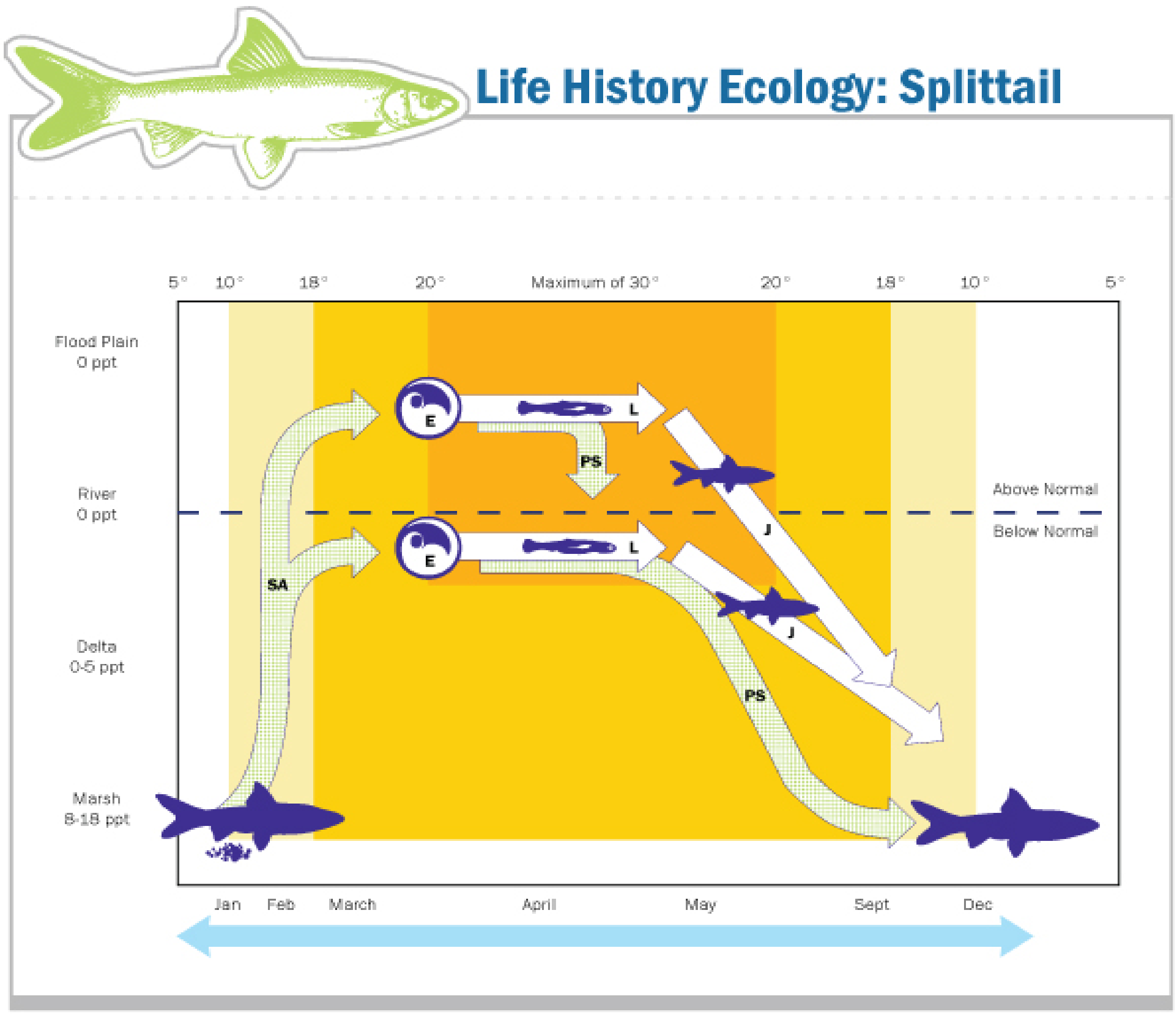

Figure 3. Life History Ecology Diagram Life history ecology diagram showing a hypothetical conceptual life history model for Sacramento splittail. Spawning Adults (SA), Post-Spawning Adults (PS), Eggs (E), Larvae (L), Juveniles (J). The blue dashed line indicates a change in spawning strategy that accompanies flooding associated with water year types. Adult fish are shaded in green.

An accurate abundance estimate of the splittail population does not exist. There are several sampling efforts that used to give an idea of the population size but, because they are not all designed to measure splittail abundance directly the results must be interpreted with caution. The gear used in some of these efforts is not intended for capture of splittail, a predominantly benthic fish found in association with marsh vegetation. Sommer et al. 2007 describes many of these efforts and gives some direction. The various sampling efforts indicate that splittail abundance varies widely for age-0 fish between years and water year types. In wet years (with large amounts of floodplain inundation) the abundance of age-0 fish can be extraordinarily high and in dry years worrying low. For adult fish (age-2+) the trends are different. The adult fish show much less variation between years, something expected from such a long lived fish. This is probably an evolutionary response to environmental stochasticity. These adult fish do show an increase in abundance two to three years after a strong year class of age-0 fish.

Adult Spawning migration (see Figure 7)

Spawning takes place on inundated floodplains (especially the Yolo Bypass, possibly the most important flood plain for splittail in the Sacramento system)) and riparian areas of rivers in submerged terrestrial vegetation (Moyle 2002). Sacramento splittail may be the most floodplain-dependent fish in the San Francisco estuary (Sommer et al. 2007). Adults begin a gradual upstream migration towards spawning areas sometime between late November and late January, but this is most evident in February thru April during high spring flow events (Moyle et al. 2004). Feyrer et al. (2006) showed that upstream migration and spawning activity are cued by changing photo period associated with the vernal equinox and or increases in flows associated with spring runoff. For cyprinids gonadal development is partially controlled by photo period (Feyrer 2006). This inundation of floodplains and riparian edges of areas upstream of Suisun Mash in the Sacramento-San Joaquin system provide feeding and spawning habitat (Moyle et al. 2004, Feyrer et. al 2006). Feeding in these areas by adults is probably important for both pre and post spawning success and survival. This migration may also occur in the Napa and Petaluma Rivers but is not monitored under the current programs. Early migrants tend to be larger fish (median FL = 293.5 mm) with later migrants being smaller (median FL = 273mm) (Moyle et al. 2004). This gives support to the hypothesis that older larger fish migrate upstream before younger smaller individuals. Mature, ripe splittail have been found in association with high turbidity, temperature below 15°C, and flooded terrestrial vegetation (Moyle et al. 2004). In late February and early March splittail begin moving onto inundated areas of the Cosumnes River floodplain. Fish stay through February and/or March to spawn on the submerged vegetation while sufficient depths and temperatures (<20°C) are maintained depending on the hydrograph (Crain et al. 2004). Flooding early in the season is not always required for adult fish to successfully spawn on inundated floodplain habitats. In 2003 the Cosumnes River floodplain was not inundated until April. Splittail were still able to move upstream to these flooded areas and spawn successfully with YOY collected in May (Moyle et al. 2004). According to Wang (1986, 1995) spawning can occur from late February to early July based on collection of larval fish. Spawning after early May is very unlikely, due to water levels and temperatures in the system. Their eggs are adhesive and stick to submerged vegetation and/or detritus until hatching (Moyle 2002, Moyle et al. 2004). When ripe splittail are ready to spawn, the males color darkens, fins develop a red tinge on their edges, and they develop white tubercles at the base of their fins and heads (Moyle 2002). In Suisun Marsh, splittail held in pens were gravid when salinities hit 1.2‰ and temperatures of 15°C (Bailey et al. 2000). Males stopped producing sperm after one month while females remained ready to spawn (Bailey et al. 2000). Bailey et al. (2000) also found that females held in indoor tanks would not mature when temperatures were held constant at temperatures of 18°C even with injections of hormones. This suggests that reproduction is partially controlled by a change in temperatures. Splittail spawning behavior has only been observed in captivity (Moyle et al 2004). Spawning in captivity occurred subsequent to routine cleaning of the holding tank that was accompanied by a drop in water level (Moyle et al. 2004). One or more males will swim along side and slightly behind a female and attempt to fertilize the released eggs as she swims through and above submerged vegetation. Channel margin riparian habitat maintains the population in dry years by providing small localized areas of inundated vegetation for spawning (Moyle et al. 2004, Feyrer et al. 2005). When floodplain inundation does not occur in the Yolo or Sutter bypasses, adult splittail must migrate farther upstream to find suitable habitat along channel margins or flood terraces that are inundated even in lower water year types; although spawning in such locations occurs in all water year types (Feyrer et al. 2005). Maintaining and increasing this type of habitat throughout the species range will help maintain genetic diversity during prolonged drought events and avoid a genetic “bottleneck”.

Early life stages - Egg/embryo **(see Figure 5)**
Fecundity for splittail varies considerably between studies which have been conducted over the past 30+ years (Moyle et al. 2004). For wild fish they range from 165 ova per mm SL with 100,800 per female, 600 ova per mm SL with 17,000 to 266,000, and 261 ova per mm SL with 150,000 per female (Moyle et al. 2004). Fish held in the laboratory for an extended period of time, showed fecundities that ranged from 24,753 to 72,314 and an average of 12.3% of body weight being egg mass (Moyle et al. 2004). This variability could be due to a wide range of environmental variables but is most likely from food variability as illustrated by the bioenergetics equation found in Moyle and Cech 2003. A recent concern for splittail is the partial shift in diet from mysid shrimp to bivalve prey and the possible bioaccumulation of selenium which is a known reproductive contaminant (Moyle et al. 2004). The most recent fecundity relationship equations are F = 0.0004 (SLmm)3.40 and F = 107.39(TWg)1.06 (Moyle et al. 2004).

This is summarized well in Moyle et al. 2004 and is reproduced below:

> Early Life History: Splittail eggs are 1.0-1.6 mm in diameter with a smooth transparent chorion (Wang 1986; Feyrer and Baxter 1998). Bailey and others (2000) found that eggs weighed an average of 1.55-2.04 mg wet weight and had an average diameter of 1.38 mm. The eggs are demersal and adhesive (Wang 1986; Bailey 1994), attaching to submerged vegetation or any other submerged substrate. At 18.5 °C they start to hatch within 3-5 days after spawning (Bailey 1994). Eggs laid in clumps hatch more quickly than individual eggs. Larvae are 5.5-6.5 mm total length (TL) when they hatch, have a yolk sac, a non-functional mouth and no eye pigment (Wang 1986, 1995; Bailey and others 2000). At 5-7 d post-hatch, they reach 7-8 mm TL, the yolk is absorbed, and feeding begins…
>
> They reach 10-11 mm in 15 days post-hatch under laboratory conditions (Bailey and others 2000). By the time they are 13-16 mm TL, they are recognizable as juveniles, with a swim bladder (Wang 1995). …

Larval downstream and Juvenile Stage **(see Figure 5)**
This is summarized well in Moyle et al. 2004 and is reproduced below:

> By the time they are 20-25 mm TL, they are easily recognizable as splittail and capable of fairly active swimming. Observations on small-scale floodplain wetlands indicate that the splittail are strongly associated with shallow edge habitat at a size of 20 mm, but gradually begin to use a variety of offshore habitats by 29 mm (Sommer and others 2002). These early life history stages also appear to show strong diel differences in behavior; at night, many young become completely benthic. They stay on the floodplain to feed and grow as long as conditions are suitable (i.e., cool, flowing water is present). On the Cosumnes River floodplain in 1998, a year in which flooding persisted well into June, juvenile splittail were common into May (K. Whitener, unpublished data). In 2000, most left abruptly over a short period in early May, when the floodplain was briefly reconnected with the river during two flow pulses produced by late rainstorms. Prior to the pulses, water had ceased flowing on to the floodplain and water temperatures had been steadily climbing. On the Cosumnes River juveniles have been observed leaving the floodplain at a size of 25-40 mm TL, when they dispersed rapidly downstream (P. Moyle, unpublished data).

Although some are swept off floodplains and downstream by flood currents (Baxter et al. 1996), many splittail larvae and juveniles remain in riparian or annual vegetation along shallow edges on floodplains as long as water temperatures remain cool (Sommer et al. 2002, Moyle et al. 2004). By about 29 mm splittail move to deeper habitats (Sommer et al. 2002). Warming water temperatures may be a cue to exit floodplains and begin downstream migration. Stranding of splittail in perennial ponds on the Yolo Bypass does not appear to be a problem (Feyrer et al. 2004). Such migrations often occur in late-April, May or even June of high flow years (Moyle et al. 2004). When these fish have reached 30-40 mm migration begins indicating a possible ontogenetic effect (Feyrer et al. 2006). These age 0 fish are 6.5 times more likely to be found in back water sloughs upstream and 3.5 times more likely to be found in inter-tidal habitats downstream than in main channel areas (Feyrer et al. 2005). Two early life history strategies occur in the Sacramento River system: the dominant one is characterized by juveniles migrating downstream in late spring and early summer to the Delta and Suisun Bay and Marsh; a less well studied strategy is to remain upstream through the summer into the next fall or spring and then migrate downstream (Baxter 1999a, Moyle et al. 2004). This latter strategy occurs in Butte Creek and the main stem Sacramento River. As the water recedes further, juveniles remaining in upstream riverine habitats congregate in large eddies for feeding (Randy Baxter unpublished data). The exact cost-benefit ratio of this particular life history strategy is unknown.

Juvenile stage to Adult (Figure 6)

Juveniles are most abundant in shallow (<2m), turbid water with a current, and are often found in small narrow sloughs lined with tules and other emergent plants (Moyle et al. 2004). Adults enter the same types of habitats and have been observed to move into shallow water < 1m with incoming tide to feed (Moyle et al 2004). Non-reproductive splittail are abundant in moderately shallow (< 4m) brackish and freshwater tidal sloughs and shoals such as found in Suisun Marsh and the margins of the lower Sacramento River (Feyrer et al. 2005; Moyle et al. 2004). Most late stage juveniles and adult splittail inhabit tidal fresh and brackish water in the Delta, Suisun Bay, Suisun Marsh, as well as the lower portions of the Napa and Petaluma rivers and their marshes (Moyle et al. 2004). Individuals of all sizes can be found in very shallow water (≤ 0.5m) foraging; particularly on a flooding tide (Randy Baxter unpublished data).

This is summarized well in Moyle et al. 2004 and is reproduced below. Figure 4 is taken from Moyle et al. 2004 (Figure 11 in original) to aid the reader of this document:

> Splittail, like other Central Valley cyprinids are relatively long-lived and reach fairly large sizes (for North American cyprinids). Analysis of scales indicates life spans of 5-7 years (Daniels and Moyle 1983) but analysis of other hard parts indicates that the largest fish may be 8-10 years old (L. Grimaldo, CDWR, unpublished data; R. Baxter, unpublished data). Both sexes reach about 110-120 mm SL in their first year, 140-160 mm in the second year, and 200- 215 mm SL in their third year, growing about 25-35 mm per year thereafter. They may reach over 400 mm SL but fish over 300 mm SL are uncommon. The largest and oldest fish are females. Growth rates, especially in the first year or two of life, may be strongly dependent on availability of high quality food, as suggested by changes in growth rate following the invasion of the overbite clam into the marsh in the 1980s. This invasion was followed by the collapse of Neomysis populations upon which splittail historically specialized (Feyrer and others 2003). When growth rates of three strong cohorts of immature fish (to year 2) in Suisun Marsh are visually compared, the growth rate of the 1980 cohort appears to be greater than that of the 1995 cohort, with the 1986 cohort showing an intermediate growth rate (Figure 11). Because splittail in Suisun Marsh grow very slowly during the cool months of October-March (e.g., change in YOY SL = 10 mm), data for these months were pooled and used in preliminary analyses comparing splittail lengths from

1979-1986 ("pre-clam") with those from 1986-1999 ("post-clam"). Pre-clam YOY (n = 2113) were significantly larger than the post-clam YOY (n = 906) and pre-clam 1+ (n = 1105) were significantly larger than the post-clam 1+ (n = 267) (T-test, 2 tailed; S. Matern and P. Moyle, unpublished data).

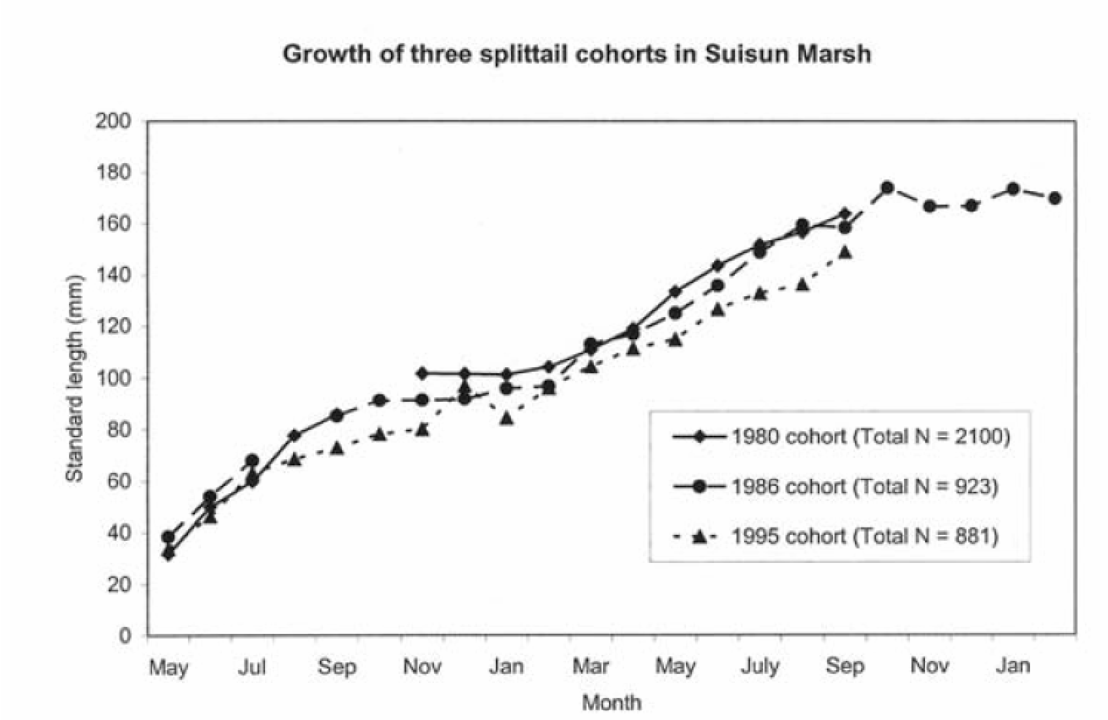

Figure 4. Growth of three cohorts of splittail for the first 22 months in Suisun Marsh, based on mean lengths from monthly samples from 1980,1985 and 1995. S Matern and P. Moyle unpublished data (Figure 11 in Moyle et al. 2004).

Stressors by life-history stage (Limiting Factors)

Modification of floodplain habitat and riverine edge/flood terrace (G): Splittail juveniles are believed to use increasing water temperatures to queue emigration; however, artificially constructed channels are often too deep to warm rapidly and splittail juveniles may get stranded by receding water. The substantial loss of floodplain from conversion to agriculture and urban areas and loss of river edge spawning habitat is probably the key limiting factor for splittail populations (Moyle et al. 2004). Splittail populations show a remarkable response to floodplain inundation as indicted by salvage during wet years following extensive floodplain inundation (Moyle et al. 2004).

Loss of riverine spawning and rearing/migration habitat (G): In the 1960s and 1970s the Army Corps of Engineers cleared and rip-rapped levees along the lower Sacramento River reducing or eliminating spawning habitat from the city of Sacramento downstream. Currently efforts are under way to improve flood protection for communities along much of the lower Sacramento River and several other valley rivers. Actions being proposed and conducted include removal of trees and riparian vegetation and armoring with rip-rap. The extensive application of riprap to the rivers for flood protection may have reduced juvenile splittail migration areas to the Delta and Suisun Marsh from spawning areas upstream. The Army Corps of Engineers current policy is for removal of all large trees and brush from levees to improve detection of weak points and failures. The Corps is working with local regulatory agencies to try to avoid the removal of all plants from levees here in California. The vegetation on the levees is the last remaining riparian habitat in the Delta and its removal would be catastrophic for numerous species.

Bioaccumulation of contaminants (C): Perhaps the greatest concern relates to Selenium. Tissues of wild caught splittail in Suisun Bay were sufficiently high in Selenium to potentially cause physiological problems, in particular reproductive abnormalities (Stewart et al. 2004). Adult splittail feed on the overbite clam (*Corbula amurensis*), which accumulates and transfers Selenium at high concentrations. With the decline of native mysid shrimp in the estuary, splittail have turned more to benthic foods such as bivalves (Feyrer et al. 2003). Young splittail, which might pick up selenium from dietary items, might also be negatively affected. Teh et al. (2004) found that young splittail fed a diet high in selenium grew significantly slower and had higher liver and muscle selenium concentrations after nine months of testing.

Toxics (C): Kuivila and Moon 2004 documented dissolved pesticides in the Sacramento-San Joaquin Delta during April-June (1998-2000) when young, growing splittail were migrating to the Delta and estuary. Since the early 1990s the use of pyrethroid pesticides has increased substantially in the Central Valley (Oros and Werner 2005). Though relatively non-toxic to mammals, it is highly toxic to aquatic organisms, including fishes. Toxicity typically occurs in the low to fractions of a part per billion (Oros and Werner 2005). Also its use on row crops (including rice) commonly grown in the Yolo and Sutter bypasses and its proclivity to adhere to particles in the water and drop to the sediment provide a dietary pathway to splittail ingestion along with detritus during feeding (see diet section above). Though there is no direct evidence, this might occur during foraging on inundated floodplains or in the estuary after the pesticides entered the water way through field drainage and were transported to and settled in the Delta. Teh et al. (2005) showed sub-lethal effects and delayed mortality to larval splittail exposed to orchard storm water runoff that contained a pyrethroid (esfenvalerate) and an organophosphate (diazinon). These fish showed higher mortality rates and slowed growth even after a three month recovery period. Combinations of low concentration toxic chemicals (Pyrethroids, Organophosphates, Organochlorines, etc.) which may have low effects on fish directly can have significant negative impacts on Chironomids (Lydy and Austin 2004), and other invertebrates (Hunt et al. 1999, Hunt et al. 2003, Amweg et al. 2005, Weston et al. 2008). Chironomids are an important food source for splittail on the floodplain where these chemicals occur. A loss of food resources at this early life stage coupled with sub-lethal toxic effects could have a substantial impact on the population but this is unknown.

Changes in Water Management (B,I): The changes in river stage resulting from diversion to storage have been little studied, but conceivably could, during low and moderate runoff years, affect splittail access to floodplains and their ability to emigrate successfully after spawning and early rearing. Increases in total and in winter water exports in the south Delta have increased salvage of a wide variety of upper estuary fishes since 2000 (Herbold et al. 2008), and may have increased salvage of age-1 and older splittail. However, the majority of splittail salvage is composed of age-0 fish, occurs May-July and occurs during years with high outflows that persist into the March-April spawning period of splittail (Sommer et al. 1997). Splittail salvage increased substantially in both 2005 and 2006, reaching a record high of over 5 million fish at the Tracy Fish Collection Facility. Post salvage survival is unknown.

Introduced (alien) species (D,F): Splittail have persisted in the estuary through numerous invasions of fishes and invertebrates. Some, such as the invasion of *Acanthomysis bowmanii* may have been beneficial as the native, *Neomysis mercedis*, was already on a steep decline. The invasion of the overbite clam (*C. amurensis*), also became a diet item, but may have detrimental bioaccumulation effects (see above). Major introduced fish predators such as striped bass and largemouth bass have been in the Delta for over a century (Dill and Cordone 1997), and splittail have persisted; however, reduced turbidity in the delta combined with increased largemouth bass habitat provided by *Egeria densa* has enhanced both the bass numbers and their ability to sight feed . A major concern is the potential invasion of the Delta by the highly predatory northern pike (*Esox lucius*). The pike, present in Lake Davis on the Feather River, is currently the target of a major eradication effort. If eradication was to fail and the pike escape to the delta, they are likely to become abundant in the same habitats used by splittail (Moyle 2002).

The following three sections are summarized well in Moyle et al. 2004 and are reproduced below (E,F):

> Fishery: One of the least appreciated aspects of the splittail migration is that they are subject to a considerable but poorly documented legal fishery from November through May. Anglers catch splittail using earthworms and cut bait. Most fish caught are kept because they are prized as food fish in Asian cuisine. Incidental data collected during creel surveys for striped bass and salmon (K. Murphy, unpublished data) suggest that at times hundreds of adult fish may be caught on a daily basis. It is possible the fishery could significantly reduce egg supply available for spawning by reducing the number of large females. However, most of the fish caught are relatively small (15-25 cm TL) so may be mostly males (J. Hileman, pers. comm.).
>
> Food Availability: Growth rates, especially in the first year or two of life, may be strongly dependent on availability of high quality food, as suggested by changes in growth rate following the invasion of the overbite clam into the marsh in the 1980s. This invasion was followed by the collapse of Neomysis populations upon which splittail historically specialized (Feyrer and others 2003).
>
> Climate Change: Global warming is occurring (Levitus and others 2000, 2001) and it will have an impact on the estuary. The most severe impacts are likely to be through changes in precipitation patterns and sea level rise. The most likely scenarios give northern California about the same amount of water but most of it comes as rain and much less is stored as snow in the Sierra. Year to year variability in precipitation will also be higher (as we are already seeing). This most likely means continued increase in large floods, increased frequency and severity of droughts, and increased difficulty of providing water for human and environmental needs. At the same time, sea level will keep rising due to melting of polar and glacial ice and thermal expansion of the ocean. A rise of 49 cm (19 in) in the next 100 years is the best estimate available of sea level rise, with a possible range of 20 to 86 cm (Warrick and others 1996). However, processes by which heat is transferred from the atmosphere to the ocean is still being assessed (Levitus and others 2001) and the role of large events, such as the 1997-1998 El Niño event, in dramatically heating the deep ocean are only beginning to be understood. It is possible that the effect of thermal expansion of the ocean is being underestimated. In the estuary, sea level rises will be amplified by tidal incursions into the narrow bays and channels because a greater volume of water will have to be squeezed into a relatively tight fixed space (Fisher and others 1979). This rise will put enormous stress on all leveed systems in the estuary, but especially in the Delta, which is almost entirely below sea level already (and many areas are 5+ m below sea level). The resulting higher tides will likely stress levees in the Delta to widespread failure, turning the Delta into a brackish bay. Suisun Bay and Suisun Marsh will become increasingly saline, resembling San Pablo Bay as it is today. Salinities in the Delta and Suisun Bay, however, will show wide variability in response to increased floods and droughts. Coupled with the stress on levees caused by rising waters is the distinct possibility of levee failure and weakening in the next few years by earthquakes (Torres and others 1999). Moreover, because the position of X2 (the 2 psu isohaline line) is related to net Delta outflow, higher sea level and concomitant higher tides will push X2 further upstream, probably resulting in decreased primary and secondary productivity (Jassby and others 1995). Fortunately, splittail will probably be able to adjust to most of the changes because the historic Central Valley and its estuary, in which they evolved, have had enormous changes through the past million or so years, both in a geologic

sense and in the sense of variability through time periods on the order of 1 to 100 years. During periods of prolonged drought the Delta would have been largely a brackish water system; Suisun Bay would have been rather saline under the same conditions. Thus the migratory behavior of splittail can be viewed as an adaptation to fluctuating conditions. Somewhere in the system there would be both flooded areas for spawning and brackish areas for rearing. Thus, under the changes predicted as the result of global warming, splittail could rear in the Delta and spawn in upstream flooded areas, such as the Sutter Bypass. They would be especially favored if levees along the Sacramento and San Joaquin rivers were set back to increase the amount of floodable land (as a way of increasing storage in flood-control reservoirs and countering the effects of sea level rise). The biggest problem they would face is likely to be the deep (3-6 m) water habitat that would dominate on flooded islands, which would be poor habitat for rearing. Thus their survival may hinge on having available large amounts of shallow tidal areas on the edges of the Delta.

Migration Barriers (H): Access on and off the flood plains are the major migration barriers that splittail face. Connectivity between floodplain and river channels is essential to the success of floodplain spawning. In addition to local access to the floodplain both adult and juvenile splittail need adequate natural edge habitats in the channels between rearing and spawning areas. The last remaining natural edge habitats should be protected and a change in riprap protocols evaluated in order to restore these migration corridors.

Disease and Parasites: When spawning males begin their migration they are often the first to arrive on the floodplains and the last to leave once spawning is over. This fact makes adult males more likely to suffer from disease and or parasites (Moyle et al. 2004) Males seldom live more than 4-5 years and post spawning mortality due to stress from parasites and or disease may be high (Moyle et al. 2004). Spawned out fish are commonly found with anchor worms and when found in the CVP/SWP fish salvage facilities have open sores on their sides (Moyle et al. 2004). These fish are probably on their way back to feeding areas in the Suisun marsh where food sources are more abundant and salinities are higher (Moyle et al. 2004). Salt is commonly used in fresh water aquaculture facilities to treat parasitic skin infections (Klinger and Floyd 2002), and returning to brackish water areas may help these fish overcome these infections and reduce osmotic stress (Moyle and Cech 2003).

Entrainment and Salvage (A): Small agricultural diversions within the planning area are not likely to have a large effect on splittail populations. Water velocities at these pumps are low and fish are able to swim past without being entrained in large numbers (Nobriga et al. 2004, Moyle and Israel 2005, Sommer et al. 2007). Power plants within the planning area have the ability to entrain large numbers of fish. Large volumes of water are pumped through the facilities which are located within splittail rearing habitat (Matica and Nobriga 2005). The State Water Project and the Central Valley Project show high rates of salvage when splittail populations are at high levels; YOY have critical swimming velocities that are near the water velocities of the large pumps and are entrained at these facilities (Young and Cech 1996). (Sommer et al. 1997, Sommer et al. 2007). When these fish are salvaged, mortalities can be quite high from over crowding within transport tanks and predation at drop off points within the Delta (Moyle et al. 2004). Actual mortality rates have not been determined. This would require mark recapture or ultra sonic tagging experiments, which have not been performed on splittail in response to salvage releases. Salvaged adults are returned to an area downstream of the pumps and farther downstream in their spawning migration. This will increase the energy needed for the fish to reach their spawning sites upriver and could reduce their ability to spawn successfully (Moyle et al. 2004).

Table 2. Stressor Description Matrix. Tables 2 and 3 do not attempt to call out all possible stressors, only stressors deemed important from a population perspective.

		A	B	C	D	E	F	G	H	I
	Habitat (*life stage*)	**Entrainment**	**Stranding**	**Toxics**	**Predation**	**Harvest**	**Food Availability**	**Habitat Loss**	**Barriers**	**Operations**
1	Floodplain/Channel Margin (*Egg/Embryo*)		Sudden dewatering	Se, Hg, Pyrethroids, Endocrine Disrupters			Less food low water year mainstem spawning	Loss of floodplains/ riprap of channel banks		Reduced Seasonal Flows
2	Floodplain/Channel Margin (*Larvae*)	SWP/CVP Small Ag	Flood plain Drainage and Connectivity	Se, Hg, Pyrethroids, Endocrine Disrupters			Less food low water year mainstem spawning	Loss of floodplains/ riprap of channel banks	Floodplain-Channel connectivity	Reduced Seasonal Flows
3	Floodplain/Channel Margin/Delta (*Juveniles*)	SWP/CVP Small Ag	Flood plain Drainage and Connectivity	Se, Hg, Pyrethroids, Endocrine Disrupters	Non-native predation	Capture for use as Bait	Less food low water year mainstem spawning	Loss of floodplains/ riprap of channel banks	Floodplain-Channel connectivity	Reduced Seasonal Flows
4	*Brackish Marsh* (*Juveniles*)	Power Plants		Se, Hg, Pyrethroids, Endocrine Disrupters	Non-native predation	Capture for use as Bait	Shift in diet with clam invasion			
5	Brackish Marsh (*Adult*)			Se, Hg, Pyrethroids, Endocrine Disrupters		Subsistence Fisherman	Shift in diet with clam invasion			
6	River (*pre-spawnAdult*)			Se, Hg, Pyrethroids, Endocrine Disrupters		Subsistence Fisherman		Loss of floodplains/rip rap of channel banks longer migrations	Floodplain-Channel connectivity	Reduced Seasonal Flows
7	Floodpalin/River (*Spawner*)		Flood plain Drainage and Connectivity	Se, Hg, Pyrethroids, Endocrine Disrupters		Subsistence Fisherman	Shift in diet with clam invasion	Loss of floodplains/rip rap of channel banks longer migrations	Floodplain-Channel connectivity	Reduced Seasonal Flows
8	River/Brackish Marsh (*Post-spawn*)			Se, Hg, Pyrethroids, Endocrine Disrupters		Subsistence Fisherman	Shift in diet with clam invasion	Loss of floodplains/rip rap of channel banks longer migrations	Floodplain-Channel connectivity	

Table 3. Stressor Understanding Matrix. Tables 2 and 3 do not attempt to call out all possible stressors, only stressors deemed important from a population perspective.

		A		B	C				D	E	F	G	H	I
	Habitat	**Entrainment**		**Stranding**	**Toxics**				**Predation**	**Harvest**	**Food Availability**	**Habitat Loss**	**Barriers**	**Operations**
	(*life stage*)	**Samll Ag**	**SWP/ CVP**		**Se**	**Hg**	**ED**	**PY**						
1	Floodplain/Channel Margin (*Egg/Embryo*)			I = 2 U = 3 P = 3	3 1 1	3 1 1	3 1 1	3 1 1			I =2 U = 3 P = 3	I =4 U = 4 P = 4		I =4 U = 4 P = 4
2	Floodplain/Channel Margin (*Larvae*)	I = 2 U = 3 P = 3	I = 3 U = 3 P = 3	I = 2 U = 3 P = 3	3 1 1	3 1 1	3 1 1	3 1 1			I =2 U = 3 P = 3	I =4 U = 4 P = 4	I =4 U = 4 P = 4	I =4 U = 4 P = 4
3	Floodplain/Channel Margin/Delta *(Juveniles)*	I = 2 U = 3 P = 3		I = 2 U = 3 P = 3	3 2 2	3 1 1	3 1 1	3 2 2	I =3 U = 2 P = 1	I =3 U = 2 P = 2	I =2 U = 3 P = 3	I =4 U = 4 P = 4	I =4 U = 4 P = 4	I =4 U = 4 P = 4
4	*Brackish Marsh* *(Juveniles)*	I = 2 U = 3 P = 3			3 2 2	3 1 1	3 1 1	3 2 2	I =3 U = 2 P = 1	I =3 U = 2 P = 2	I =2 U = 3 P = 3			
5	Brackish Marsh (*Adult*)				3 2 2	3 1 1	3 1 1	3 2 2		I =3 U = 2 P = 2	I =2 U = 3 P = 3			
6	River (*pre-spawnAdult*)				3 2 2	3 1 1	3 1 1	3 2 2		I =3 U = 2 P = 2		I =3 U =2 P = 2	I =4 U = 4 P = 4	I =4 U = 4 P = 4
7	Floodpalin/River (*Spawner*)			I = 2 U = 3 P = 3	3 2 2	3 1 1	3 1 1	3 2 2		I =3 U = 2 P = 2	I =2 U = 3 P = 3	I =4 U = 4 P = 4	I =4 U = 4 P = 4	I =4 U = 4 P = 4
8	River/Brackish Marsh (*Post-spawn*)				3 2 2	3 1 1	3 1 1	3 2 2		I =3 U = 2 P = 2	I =2 U = 3 P = 3	I =3 U =2 P = 2	I =4 U = 4 P = 4	

Future Research

The following is reproduced from Moyle et al. 2004:

> [1]Develop a Systematic Research Program: The hypotheses in this paper indicate that there are many unanswered questions that bear on management. Particularly useful would be radio telemetry and marking studies to track migrations, to determine fidelity to spawning areas, to monitor survival of fish salvaged at the pumping plants and to locate important feeding and spawning areas. As battery technology improves, telemetry studies become more feasible. The information developed here needs to be used in hydrodynamic models of the estuary to determine if changes in flow regime affect movements of splittail between spawning and rearing areas. There is also a need for genetic studies to help determine if more than one population exists in the estuary.
>
> Continue to Use Simulation Models: Potential impacts on splittail of diversions to storage and large, rapid reductions in dam discharge have not been evaluated although appropriate information has only recently become available (Sacramento and San Joaquin River Basins Comprehensive Study, ACE). GIS and survey data should be reviewed to identify floodplain and terrace locations potentially important to splittail. Models should then be run to determine critical flows for maintenance of inundation. Such information, could be used to assess potential impacts (e.g., drying up flooded areas) and to investigate alternative flow management strategies.

Genetic and otolith microchemistry research: The Napa and Peteluma Marsh population may be important for population level production (Feyrer et al. 2005). While these stocks have been identified as genetically distinct from the Sacramento-San Joaquin population (Baerwald et al. 2005), their influence on the entire species population is unknown. A combination of genetic research and otolith microchemistry could be used to identify the exact population structure throughout splittail's geographic range (Feyrer et al. 2007). The otolith microchemistry results could be combined with contaminant exposure biomarkers and splittail could then be effectively used as an indicator species, for example toxic contaminants or changes in the food web, given the current low abundance of delta smelt and longfin smelt.

The following is reproduced from Moyle et al. 2004:

> Improve Estimates of Splittail Abundance: The various fish surveys in the estuary together can be used to provide reasonably good indications of splittail abundance trends, especially for YOY. Individually, most of the surveys suffer from not being designed to sample splittail. The U.C. Davis Suisun Marsh survey most consistently collects all size classes of splittail but the trends for YOY are not always consistent with other surveys. There is thus a need to investigate either the development of a splittail-specific survey or to find ways to improve existing surveys to sample splittail better. For example, USFWS seining surveys could sample additional locations to better assess production in the rivers. Trawling surveys might be able to add stations in shallower areas or near splittail spawning areas. It might also be useful to develop an index of abundance of spawning (adult) fish. A mark-recapture program similar to that for striped bass would likely be the most accurate means to assess adult population size, but would be very expensive. A second approach involves verifying methods of aging splittail, then implementing a means of consistently sampling the adult population annually. By consistently collecting, sexing and aging fish over a short discrete period annually – such as during the spawning migration – over time the resulting data would allow determination of the relative size of each year class and

[1] The hypotheses indicated in this section can be found in Moyle et al. 2004 pages 24 - 32.

its potential contribution to reproduction in each year. Although this information might not provide a good estimate of current population size, it would likely provide insights into factors influencing population trends and in particular the relative contributions of wet and dry year, year classes to the population. [In addition to the research described above the following are needed as well. Under the current sampling programs splittail are an incidental catch. There is no system wide sampling program that targets splittail specifically. Possibilities include fyke nets at the return ends of floodplains to identify recruitment from floodplain spawning, bottom oriented otter trawls to target upstream migrating adults or downstream migrating juveniles.]

Protect and Enhance Remaining Floodplains and Flood Terraces: In recent years, as CALFED planned riparian restoration projects, the U.S. Army Corps of Engineers (ACE) has been proposing to clear and rip-rap sections of Sacramento River flood-terrace which presently support some of the last remaining riparian forests and splittail spawning habitat. Such areas may be critical for the limited spawning of splittail that takes place in dry years. Habitat restoration is too expensive to allow valuable habitat to be destroyed when other options may be available.

Provide Additional Access to Floodplains: Expansion of easily inundated floodplain habitat should enhance splittail reproduction and abundance, provided new areas are designed to drain properly and lack extensive areas of permanent water to harbor potential predatory fish.

Manage the Yolo and Sutter Bypasses to Benefit Splittail and Other Native Fishes: The Yolo Bypass is clearly a major splittail spawning area and there is strong indication that even partial flooding for a sufficient period can result in successful spawning and rearing by splittail, even in dry years. Ongoing studies of splittail use of the Yolo Bypass should continue, including investigations of creation of spawning and rearing areas in non-flood years. Investigations should also continue on ways to improve the frequency and duration of flows through the bypass (e.g., with gates on the Fremont Weir) for the benefit of splittail and other native fishes. The importance of Sutter Bypass to splittail is less clear but it does have some value for spawning and rearing. This needs to be documented better and ways found to manage the bypass to favor native fishes. [This approach should be used in other floodplain areas throughout the system (San Joaquin, Napa, Cosumnes) as well. This could be one of the most important restoration actions in the entire system.]

Provide Additional Channel Margin Habitat for Juveniles: Shallow margins of Delta channels appear to be important for migration and rearing of juvenile splittail. There is first a need for basic information on the kinds of habitat juvenile splittail use and how they use it, both seasonally and permanently. Means to increase suitable habitat then need to be determined, such as setting back levees, reclaiming islands as aquatic habitat, and breaching levees in marshy areas.

Provide Additional Brackish Water Rearing Habitat for Juveniles: Recent studies suggest that shallow, tidal, brackish water channels along Suisun Bay may be important rearing habitat for splittail. The characteristics of suitable rearing habitat need to be determined and incorporated into marsh restoration projects.

Evaluate Losses of Splittail at State Water Project and Central Valley Project Pumping Plants: The pumping plants in the south Delta capture large numbers of splittail in all life history stages, especially in wet years when splittail are most abundant. However, it is not known (1) what proportion of captured fish are mortalities, (2) if there are high mortalities from predation on fish drawn towards the plants, (3) if capture of adult fish affects their ability to spawn, and (4) if mortalities at the pumping plants have any impact on splittail populations. [(5) The efficacy of trucking including cost and predator induce mortality at the release sites.]

Develop (and Implement) Strategies to Reduce Entrainment Mortality: Splittail larvae and juveniles are entrained not only by the CVP and SWP pumps but probably by the Antioch and Pittsburg Power Plants and other diversions in the Delta. There is still a need to understand what impact these diversions have, if any, on splittail populations. Impacts are most likely to be significant in dry years when a higher percentage of the water is diverted and splittail populations are depleted.

Reduce Pollutant Input, Particularly of Contaminants: Recent evidence indicates adult splittail may be accumulating selenium in concentrations detrimental to reproduction, presumably by consuming the introduced overbite clam (R. Stewart, pers. comm.). There is a need to investigate further the effects of selenium and other contaminants on splittail and to find ways to reduce sources. For example, alternatives to dispose of agricultural drain water from the western San Joaquin Valley include transport and dumping into Suisun Bay. Such an eventuality, without a similar reduction in industrial input, could result in impaired reproductive function in splittail.

Develop a Management Plan for the Fishery on Spawning Migrants: A fishery management plan should be established for splittail to limit the fishery impact on spawners. The fishery should be restricted during drought years.

Important information gaps: Accurate abundance estimates, environmental tolerances of larva and eggs and toxic effects on floodplains from pesticides; selenium and mercury bioaccumulation, and endocrine disrupters; the importance of the Napa and Petaluma Marsh to the structure of the population; trophic transfer of nutrients to the food web; the process of growth, recruitment, and survival throughout splittail life history; genetic distinction and site fidelity between watersheds.

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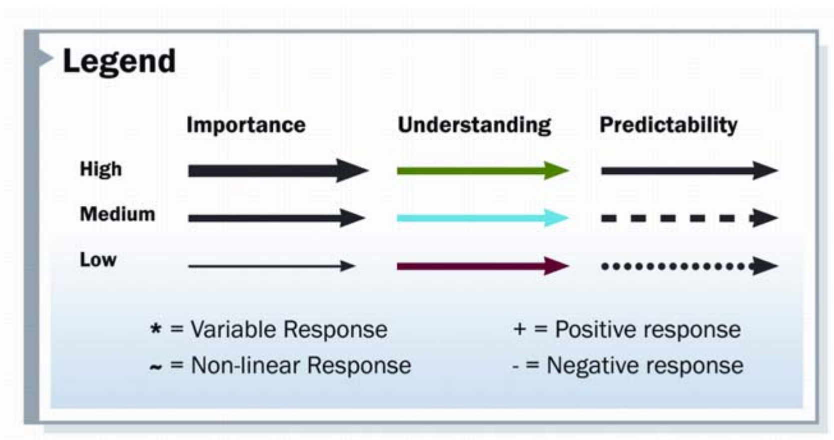
Life History Figures

Figures 5, Depicts life history of splittail under dry and wet conditions.

Figures. 6, 7 and 8 depict life stage transitions matrices.

The arrows (see key below) associated with the sub-models in Figures 5-8 depict the importance of the processes the level of understanding of the processes and the predictability of the processes. A plus sign indicates a positive effect on the transition probability, while a minus sign a negative one.



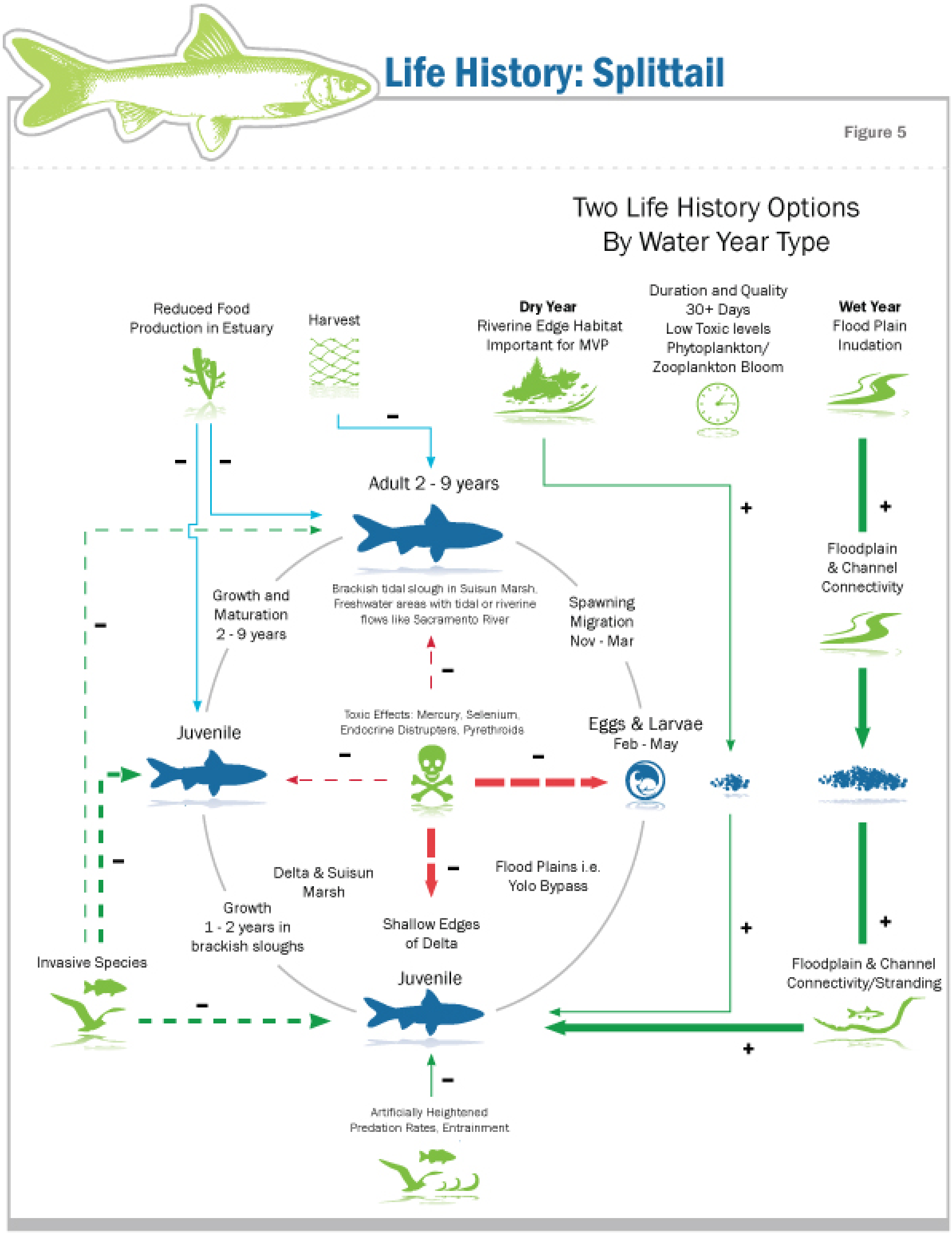


Figure 5. Sacramento Splittail Life History Stressor Model

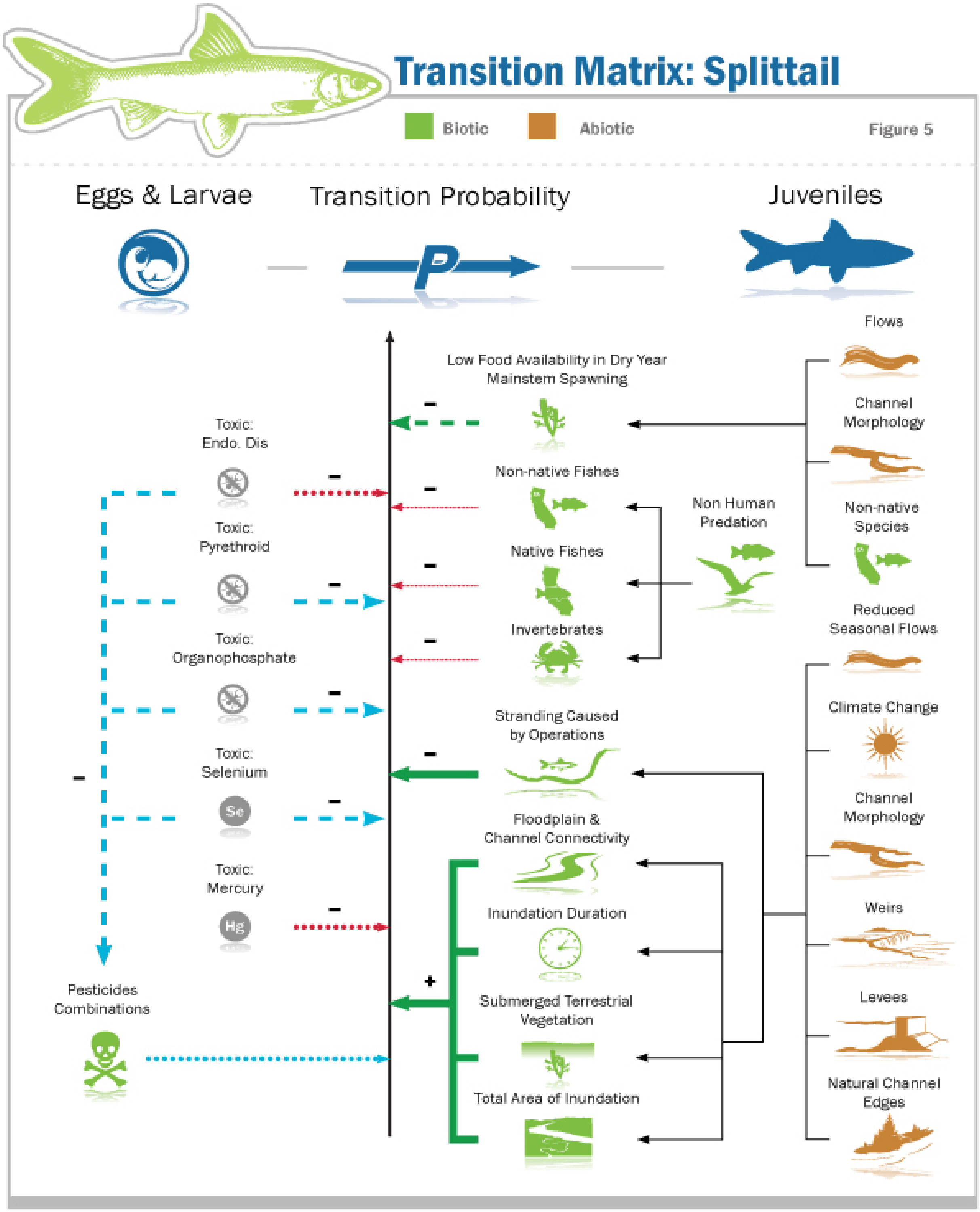


Figure 6. Sacramento Splittail Life History Stressor Sub-Model The arrows associated with these sub-models are described in key 5. A plus sign indicates a positive effect on the transition probability, while a minus sign a negative one.

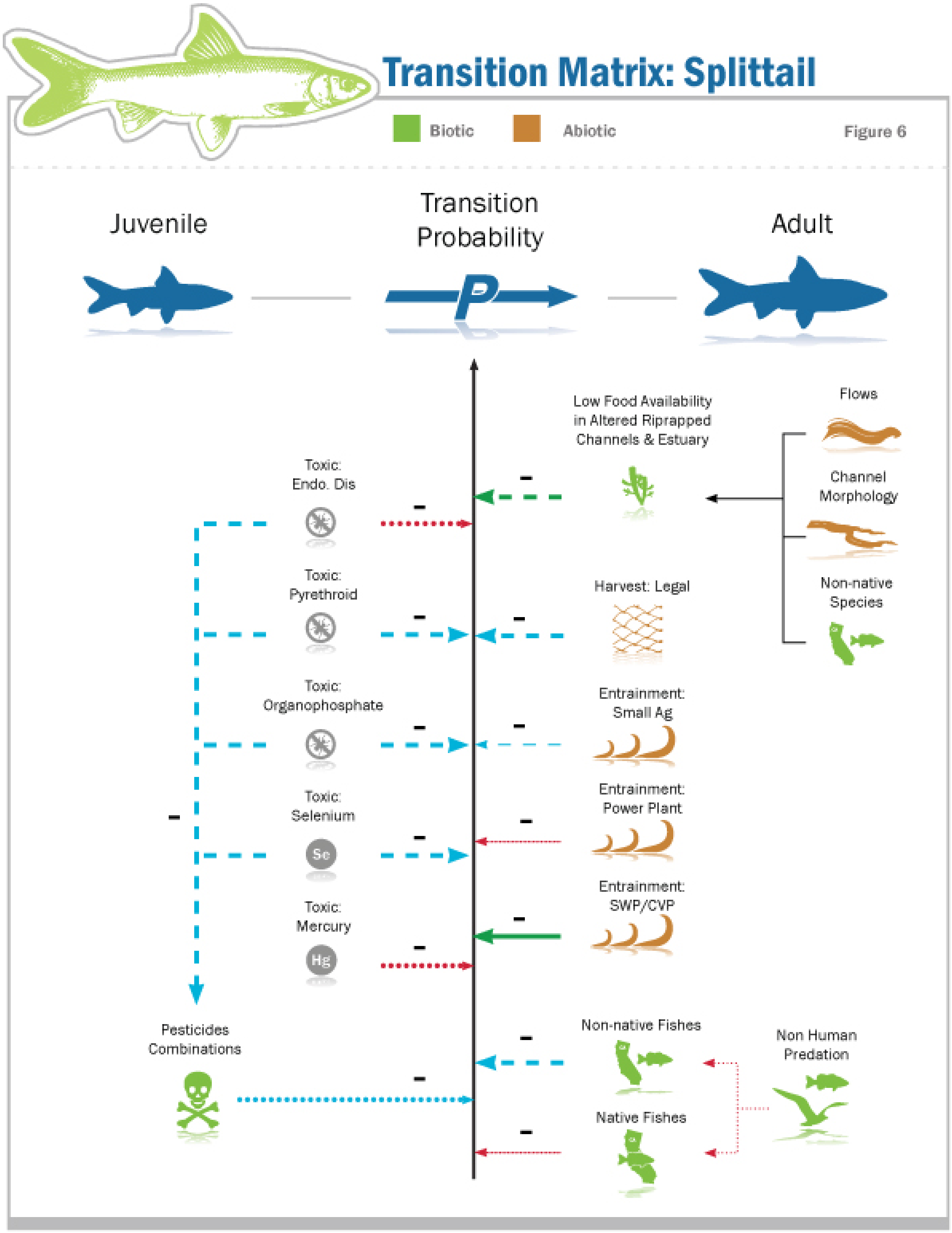


Figure 7. Sacramento Splittail Life history Stressor Sub-Model.

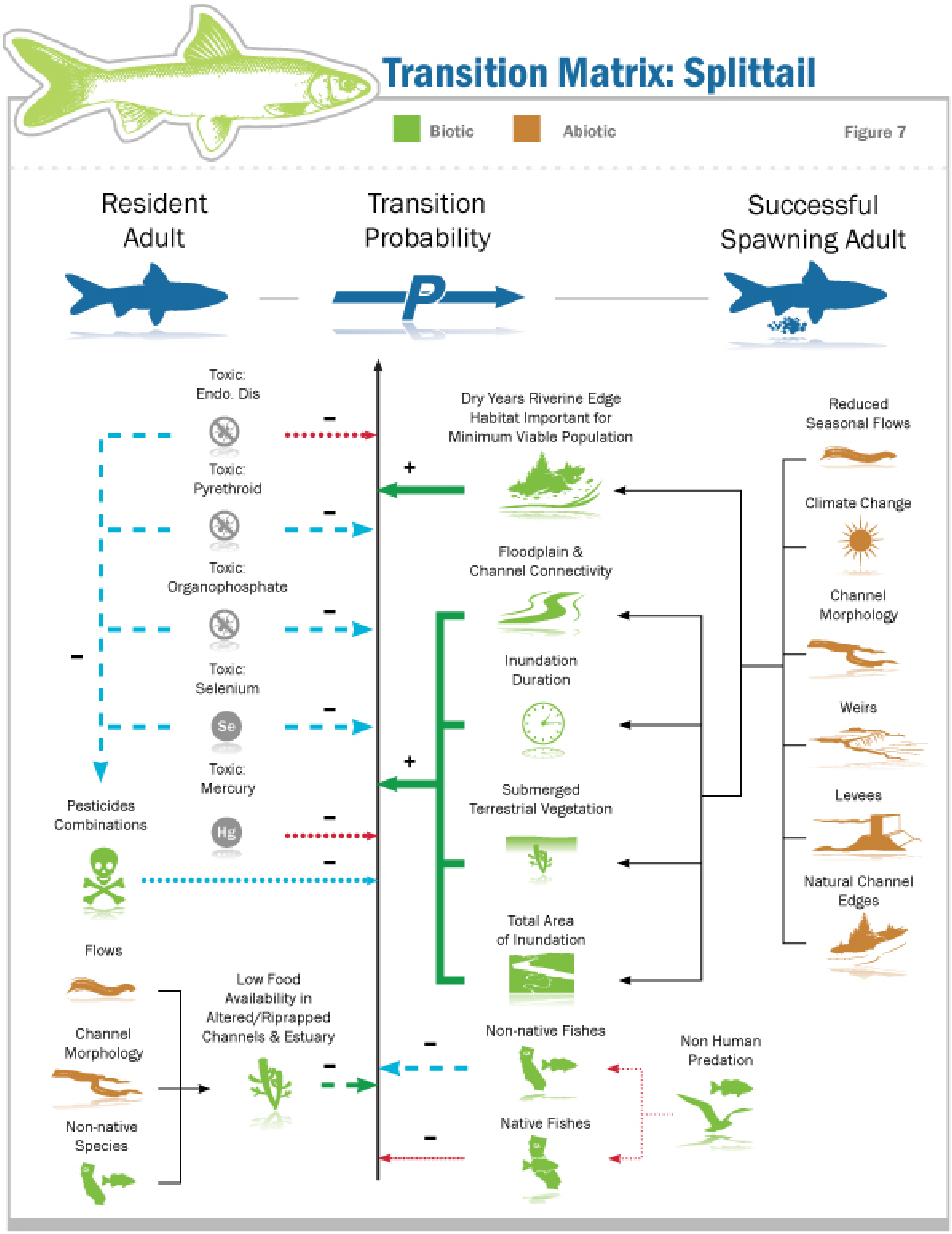


Figure 8. Sacramento Splittail Life History Stressor Sub-Model.